N89-15601

A Very Large Area Network (VLAN) Knowledge-base applied to Space Communication Problems

Carol S. Zander

Department of Computer Science
Colorado State University
Ft. Collins, CO 80523

ABSTRACT

This paper first describes a hierarchical model for very large area networks (VLAN). Space communication problems whose solutions could profit by the model are discussed and then an enhanced version of this model incorporating the knowledge needed for the missile detection-destruction problem is presented.

A satellite network or VLAN is a network which includes at least one satellite. Due to the complexity, a compromise between fully centralized and fully distributed network management has been adopted. Network nodes are assigned to a physically localized group, called a "partition." Partitions consist of groups of "cell" nodes with one cell node acting as the organizer or master, called the "Group Master" (GM). Coordinating the group masters is a "Partition Master" (PM). Knowledge is also distributed hierarchically existing in at least two nodes. Each satellite node has a back-up earth node. Knowledge must be distributed in such a way so as to minimize information loss when a node fails. Thus the model is hierarchical both physically and informationally.

1. Introduction

Distributed problem solving networks provide an interesting and powerful base for solving those problems for which a single problem solver or single machine seems inappropriate. Problems requiring world-wide support, involving network nodes in space fall into that category. While local area and wide area networks currently solve many distributed problems, satellites provide expanded capabilities unavailable with local and wide area networks. In the past, satellites have mostly been simply a reflector of signals, computationally passive in computing networks. However, with the rapid advancement of technology, it is conceivable that in the near future satellites will have on-board computing power. Satellites may contain a single computer or a local area network.

A network containing one or more satellites is classified as a Very Large Area Network (VLAN). Problems that will be solved using the VLAN model are extremely complex in part due to the large spatial distribution of nodes. To manage the network and control the information distributed throughout the system, artificial intelligence techniques are needed. A knowledge-based system manager handles the duties of resource management and network communication. This paper introduces the VLAN model and applications, but details of the manager will be presented in later work.

In the next section, the VLAN model is presented with its organization: the hierarchy of communications within the network, the management of the hierarchy, and fault tolerance considerations. Space communication problems are then discussed. Suitable applications are briefly introduced with the paper focusing on the missile detection-destruction problem in a VLAN environment.

2. The VLAN Model

2.1 Model Design Issues

When designing the VLAN model, many issues must be considered. There are design questions about information flow, control knowledge distribution, and domain knowledge distribution. While the flow of information is not dependent on a particular problem, it is dependent on the communication plan of the network. Control knowledge can be handled in a general way in the knowledge base, but content and distribution of domain knowledge is problem specific. Should communication and knowledge be fully centralized or fully distributed? Should knowledge be redundant at nodes? This paper contains some preliminary results, but the full-blown knowledge base will be done in future work.

2.2 Organization of the VLAN Model

The complexity of a network of this size is so great that a fully centralized design must be ruled out. Similarly, a fully distributed design is also unreasonable as it would take too long to find and pass information. Thus, a trade-off between a fully centralized and fully distributed design is adopted.

The model design is described here, but has been altered from the original model found in [5] so that it is adaptable to the applications considered here. For a discussion on communication protocols for VLANs, see [3]. A general VLAN has no restrictions on the number of nodes or their positions, physically or within the network. There are four general kinds of nodes:

1. Fixed nodes stationed on earth.
2. Mobile earth nodes -- land, water, air vehicles.
3. Geosynchronous satellites.
4. Non-geosynchronous satellites.

Given the different kinds of nodes in the network and the possibly very different tasks that these nodes will accomplish, nodes are grouped together functionally based on tasks. In the general model, it is assumed that each node is responsible for a set of very specific tasks as well as some general support. Thus, each node is assigned membership in one or more functional group based on its responsibilities. The task may be some specific computational need or some managerial function. These groups are totally functional, and not physical.

2.2.1 Communication Hierarchy

Because the physical distribution of nodes could differ greatly from the functional distribution of nodes, direct communication with each other may be impossible. So in addition to the functional groupings, the network nodes are also assigned to a physically localized group, called a "partition". That is, physical space is divided into partitions made up of nodes located physically in the same proximity. Within each partition are nodes from some functional group, physically splitting the functional groups into parts. Therefore a partition is comprised of possibly many functional subgroups which will be referred to as local functional groups. Each node is a member of exactly one physical partition, but may be a member of more than one functional group. A sample VLAN, illustrating three physical partitions and two functional groups is shown in figure 1. The naming, subscripting, and superscripting scheme explanation follows.

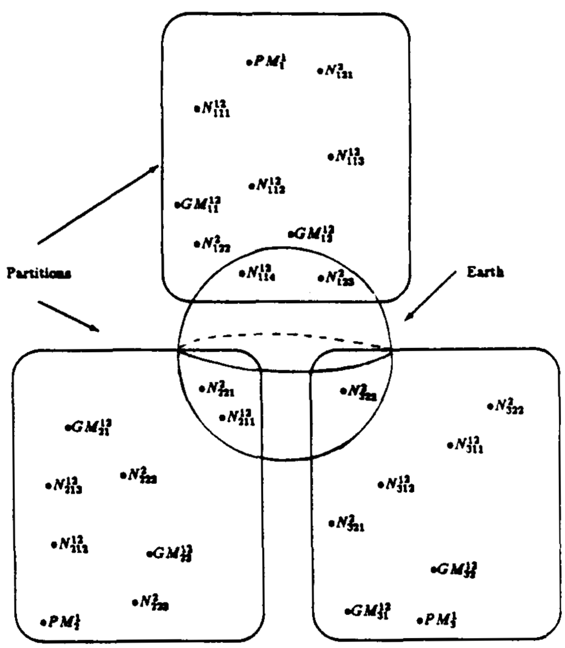

Figure 1: *VLAN* with 3 Partitions and 2 Functional Groups

Each node in a partition is called a "cell" node. In figures, cell nodes are labeled with an N. For communication purposes, each cell node is part of one local functional group. One of the cell nodes is chosen as the master node per local functional group in each partition, and is called a "group master node" or just Group Master (GM) and is labeled in figures by a GM. Thus, each partition contains one group master for each local functional group represented in that partition. Again within the partition, one of the cell nodes is given the duty of master over the group masters and is called the "Partition Master" (PM) and is labeled in figures by a PM.

Thus, each partition has exactly one partition master which communicates with group masters. Each local functional group has exactly one group master which communicates with cell nodes in that group. This forms a hierarchy of communication from PMs to GMs to cell nodes. To correspond from one partition to another, partition masters communicate. The subscripting and superscripting scheme in figures is as follows. For all nodes -- PMs, GMs, and cell nodes -- all digits in the superscript say which functional groups the node belongs to. PMs have one subscript, simply taken from a sequential numbering of all partitions and representing their respective partition number. GMs have two subscripts, the first adopts the subscript of their PM indicating their partition number, and a second subscript represents the local functional group the GM is a part of. Similarly, cell nodes have three subscripts, saying which partition and which local functional group the cell node is in and then an identifying number within the local group. Since the superscript lists all functional groups the node is a member of, the second subscript of group masters and cell nodes must be contained in that list. A representation of the communication hierarchy with two partitions is found in figure 2.

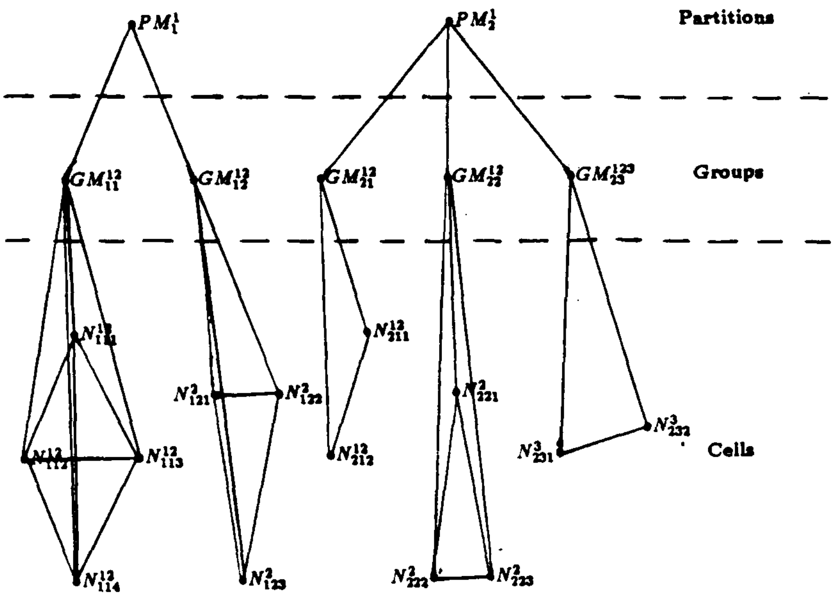

Figure 2: Communication Hierarchy of a *VLAN*

2.2.2 Management Hierarchy

The last section introduced the communication hierarchy of the network, and now the management issues are addressed. At a high level, a group master manages all operations of its group's cell nodes, and is the communication link between the cell nodes and its partition master.

A partition master coordinates communications between local functional groups in its partition and communicates with all other partition masters. It is assumed that partition masters will be on board geosynchronous satellites. There is less interference for satellite to satellite communication than with that of earth to earth or satellite to earth communications. An earth node is designated as a back-up or stand-by partition master to assure continuation of the system in case of failure. Because mobile earth nodes are not fixed and their location can be readily changed so that they are not predictably located, this node type will take on the important role of back-up node.

In the general model, management of direct communication takes place as follows:

> A cell node may initiate direct communication with its group master, or directly with another cell node in its local functional group only if initiated by its group master.
>
> A group master may initiate direct communications with any cell node in its localized functional group, or with its partition master.
>
> A partition master may initiate direct communications with a group master in its partition, or another partition master.
>
> Under special circumstances (eg., failure of a supervisory group master), a cell node may initiate direct communications with its partition master to notify of the failure. The partition master may then initiate direct communications with a cell node to promote it to group master status.
>
> Similarly, a group master may initiate direct communications with another partition master to notify it of failure.

2.2.3 Fault Tolerance

In the general model, when a cell node "determines" that its group master has failed, it directly informs that group master's partition master of the suspected failure. After "verifying" the failure, the partition master appoints one of the remaining cell nodes in the functional group as the new group master. The knowledge base is updated.

A similar dynamic fault tolerance scheme exists for partition master failures. A group master determines its partition master has failed. If the partition master is the original satellite node which has failed, then its earth duplicate is notified and after checking to make sure of definite failure, either it assumes partition master duties or assigns the duties to another geosynchronous satellite.

3. Space Communication Problems

3.1 Suitable Problems

The VLAN model design lends itself well for use with physically large distributed problems. Since most space communication problems fall into this category, the VLAN model is ideal to use as a framework to handle these problems. It is organized in such a way that a complex management system can be neatly imbedded in the network.

Many distributed artificial intelligence systems have been developed over the years in such areas as medical diagnosis, natural language processing, and manufacturing. (See [1] for a concise survey.) The VLAN is inappropriate for these smaller problems, but is a way to handle the physically larger problems.

One suitable application is space traffic control, the problem consisting of an airspace of space stations with spacecrafts arriving and leaving at fixed entry and exit points. Another problem is the vehicle monitoring problem. Here, a map is to be created from sensors picking up signals from or sounds of moving vehicles in space. The VLAN could be used for the business application of foreign exchange trading, communicating information around the world in real-time. Many military problems involve space with one foremost problem being the missile detection-destruction problem. The rest of the paper focuses on this problem.

3.2 The Missile Detection-Destruction Problem

One of the most interesting, complex problems suitable for the VLAN model is the missile problem. Simply put, it is the problem of detecting an incoming missile, computing it's trajectory, and ultimately destroying the missile. The network must carry out the essential functions of surveillance, trajectory determination, discrimination and assessment; aiming and tracking of nodes; interception and destruction; and management. The system must perform tasks in a fast and efficient manner and be fault tolerant, continuing functioning for as long as possible after any node failure.

The system is designed to intercept a missile in all four phases of its flight: the boost, post-boost, midcourse and terminal phases [4]. The boost phase is brief, lasting approximately 50-300 seconds and occurring 200 km above the earth's surface. The boost phase is followed by the post-boost or bussing phase. In this phase the bus (last stage of the missile) is already in a trajectory, and releases many reentry vehicles and decoys, lasting 5 minutes. In the midcourse phase, now 1000 km above the earth, the warheads and decoys are traveling in an unpowered trajectory. The midcourse phase lasts 20 minutes. In the terminal phase, a time of one to several minutes, the atmosphere is reentered and the decoys are stripped away by air resistance. The four phases are illustrated in Figure 3.

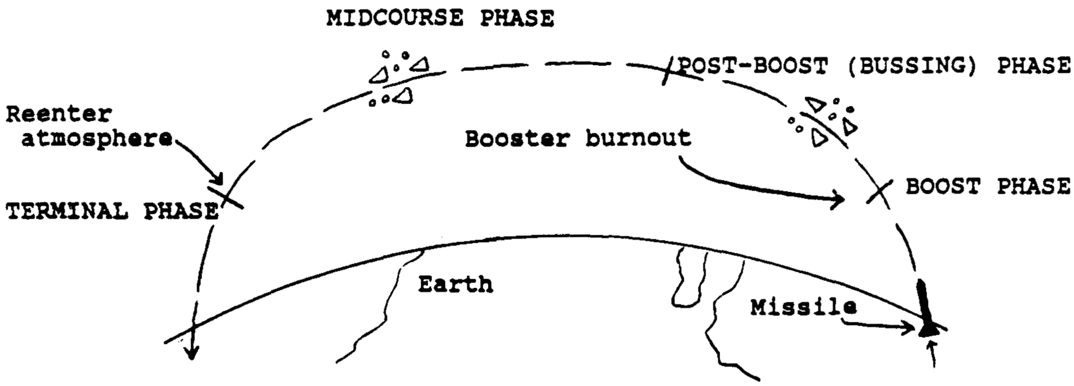

Figure 3. Four Phases of a Missile Flight.

3.2.1 The VLAN Functional Groups and Partition Structure

The first consideration of incorporating the missile problem into the VLAN model is to determine the functional groups. The needs of the missile problem dictate most of the functions.

At the crux of the problem are the functions of missile detection and destruction. The function of detection includes sending a warning to appropriate nodes or group managers, determining the source of the missile, and anticipating the projected target. The warning is to alert group managers that computation and destruction nodes under their supervision are about to be invoked. This gives them a head-start in figuring out which node should be chosen to destroy the missile. The source of the missile and the target are useful pieces of information for anticipating future missile onsets. Since this information must be kept in the knowledge-base associated with the VLAN, messages of information must be sent to the record keeping nodes.

When a missile is detected, its trajectory must be computed for use by destruction nodes. Thus trajectory computation is a necessary, important function needing fast, dedicated computers. This function will be divided into subfunctions depending on the phases of a missile's flight time, the boost, post-boost, midcourse, and terminal phases. There are also four functions associated with destruction corresponding with the four phases. Different kinds of nodes are necessary for the different phases.

Other functions include the detection of failing nodes and destroyed nodes and the updating of the knowledge-base.

Successful destruction of missiles is useful information for guidance of destruction of future missiles. If technologically possible, a decoy-warhead discriminating function could be incorporated in the VLAN. Some nodes will be dedicated strictly as protection nodes, protecting other, critical nodes. Acting as a back-up node constitutes a functional group, as well as the function of decoy satellites. In addition, there will be many kinds of management nodes. These handle the duties of keeping and controlling the knowledge-base and managing the VLAN network.

To be able to approach real time response, the VLAN hierarchy is necessary for handling the complicated duties of management. For example, if a missile is detected, the detection node communicates with its group master who either finds nodes under its command to finish the destruction, contacts other group master nodes, or contacts its partition master. There are fewer communication links to accomplish the task and they can be done in parallel to assure completion. The hierarchy is based on an information need rather than standard network traffic.

All the functional groups will be represented in each partition. The number of nodes representing some functional groups will be based on the number of nodes from some key groups. The key groups include missile detection, missile destruction, and management nodes. The exact numbers for these key nodes are not yet determined, but there have been estimates made for similar problems, see [2] and [4]. One difficulty of the VLAN model, common to all space network systems, is the changing configuration of the partition structure. Unless a satellite is in geosynchronous orbit, it will not be stationary above a point on the earth, but will trace a track which rotates around the earth. There must be enough satellites in each partition so there are always necessary nodes within intercept range of any missile.

Numbers of trajectory computation, node failing detection, and decoy discrimination nodes will depend on the number of missile detection nodes. The amount of missile destruction nodes will determine quantities of node failing detection nodes as well and destruction detection. Protection and back-up nodes will mostly depend on how many management nodes there are. Decoy satellites are not dependent on any particular key nodes, and are not key nodes themselves, but are dependent on the total number of nodes in a partition. Their numbers will be in a proportion so as to make it difficult to determine the real nodes.

3.2.2 Problem Knowledge

The domain knowledge of the missile problem includes many pieces, the most important being the topology of the VLAN, that is, the partition division and the numbers and positions of nodes. This information is distributed amongst the management nodes and their back-up nodes. When nodes dynamically fail, the news of the failure is broadcast to all group managers.

4. Conclusions

This paper introduces a very large area network as a framework for solving spatially large distributed problems. A VLAN is composed of cell nodes, group masters, and partition masters with the partition masters managing the group masters in their partitions, and the group masters managing the cell nodes in their localized groups. All nodes belong to some functional group based on the tasks they perform. The key elements of the model design are the communication and management hierarchical organization, with the motivation for the hierarchies to simplify the complexity of the network. The VLAN model is designed to be fault tolerant for as long as possible.

This distributed approach to solving problems is powerful with much potential for solving futuristic distributed problems. The VLAN model with its organization is well suited as an environment for handling these problems. Several possible problems were introduced with a focus on one foremost problem, the missile detection-destruction problem. This problem was outlined and incorporated into the VLAN model.

There is still much work to complete the incorporation of the missile problem into the VLAN model. Domain knowledge needs more detail and precise placement in the model and control knowledge must be totally defined and distributed in the network. The preliminary employment of the VLAN model for use with distributed problems is promising.

References

[1] Decker K. S., Distributed Problem-Solving Techniques: A Survey, IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-17, No. 5, Sept/Oct 1987, pp. 729-740.

[2] Guertner G. L. and Snow D. H., The Last Frontier, D. C. Heath and Company, Lexington, Massachusetts, 1986.

[3] Oliver S. R. and Wolf J. J., Characterizing Very Large Networks (VLAN), Proceedings of Computer Networking Symposium, Addendum, Oct 1986.

[4] Schroeer D., Directed-Energy Weapons and Strategic Defence: A Primer, Halstan & Company Ltd., Amersham, Bucks, Great Britain, Adelphi Paper 221, 1987.

[5] Wolf J. J. and Ghosh B., Modeling Very Large Area Networks (VLAN) using an Information Flow Approach, IEEE Proceedings of the Symposium on the Simulation of Computer Networks, Colorado Springs, Colorado, 1987.